



Material Characteristics for an Analytic Hypervelocity Impact Performance Model

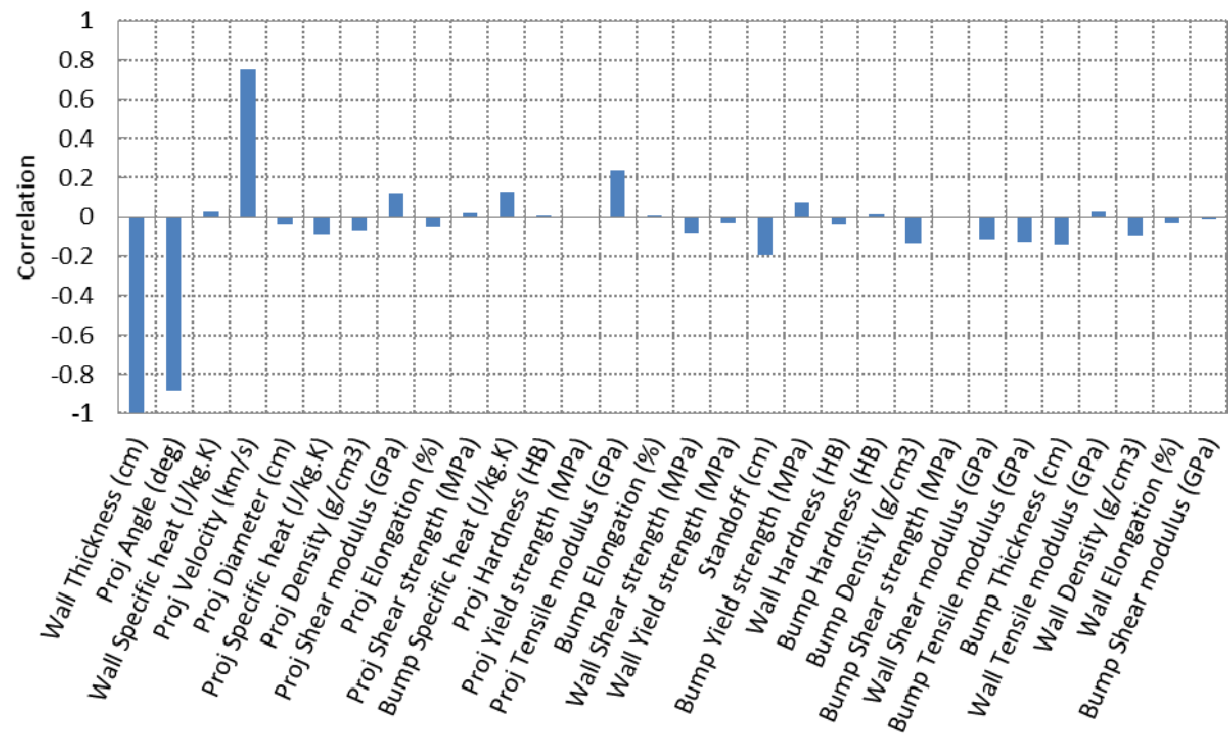
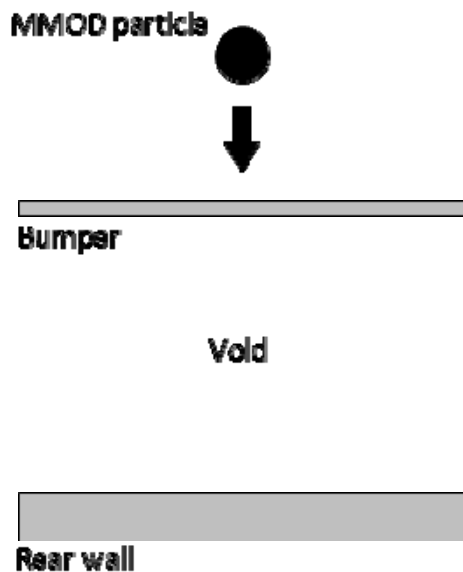
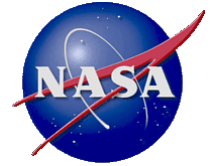
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June 11, 2015

An approach to derive material inputs has been developed for use within analytic ballistic performance models

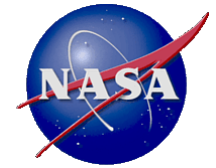


- A large database of over 1,100 impact tests into two wall shields has been gathered to evaluate performance dependence on material properties
 - Big data analytics including Artificial Neural Networks (ANN) have been used to probe the dataset
 - From ANN many key shield characteristic effects have been quantified
- Insights from the dataset have been used to examine important parameters for the impact event
 - Material properties needed for impedance match principles to calculate residual velocity
 - Material properties needed for thermal properties and wave speeds for expansion
- Using this approach, improved extrapolations have been achieved across the large database of impact conditions over a broad range of materials and arrangements
- Matching these energy estimates with path dependent simulations have increased the understanding of simulation results

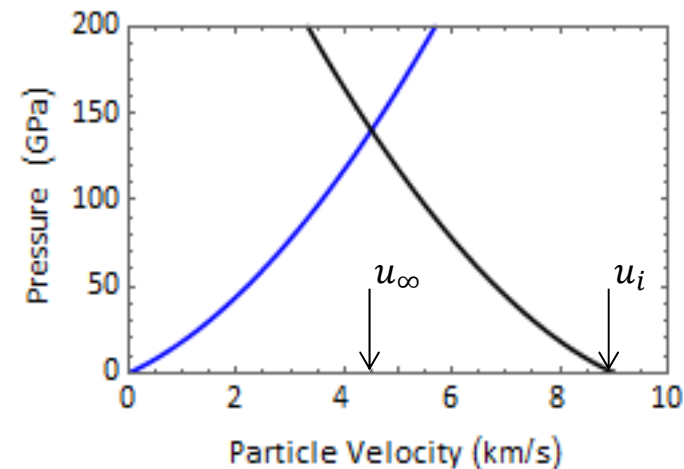
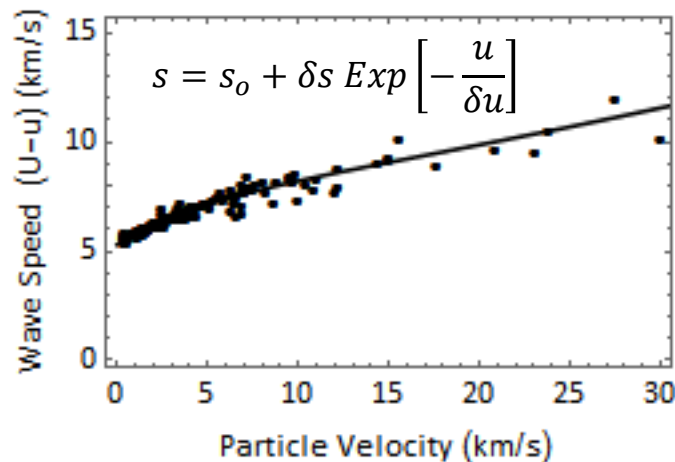
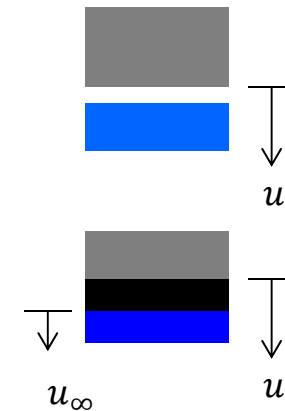
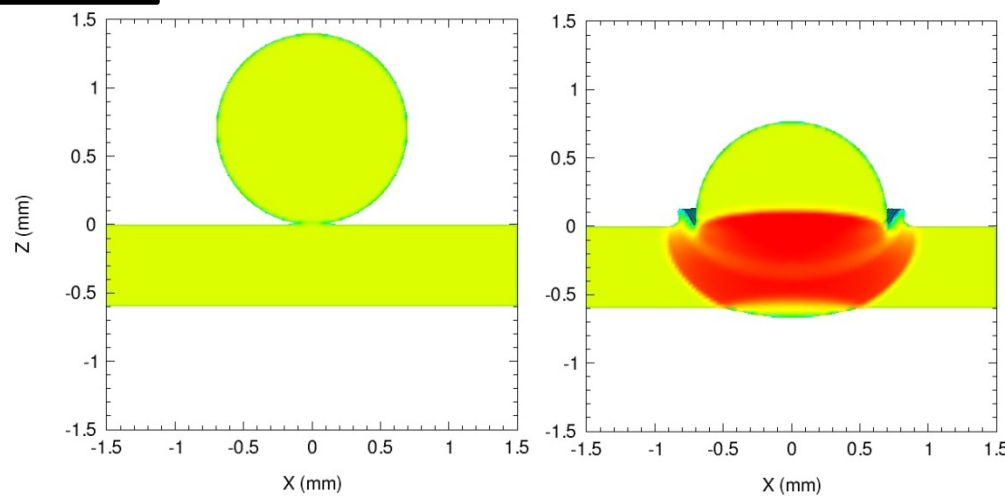
Double wall shields have been integral in maintaining reliability in the solid particle environment and ANN data analytics have yielded shield performance metrics



Shock wave parameters are derived from a non-constant slope in the linear kinematic model for wall interactions

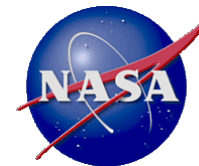


Aluminum

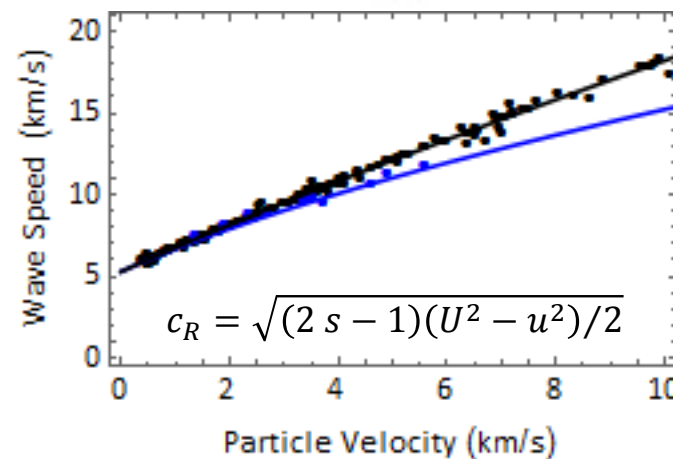
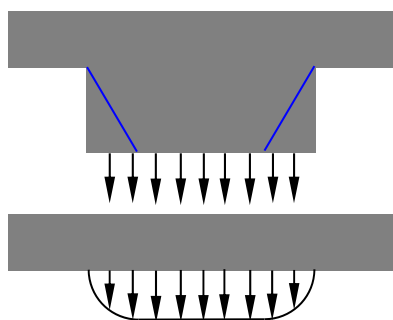
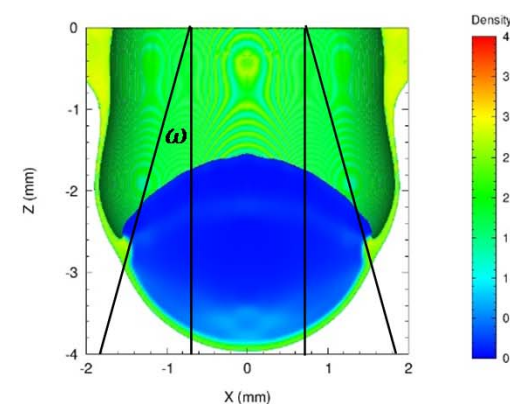
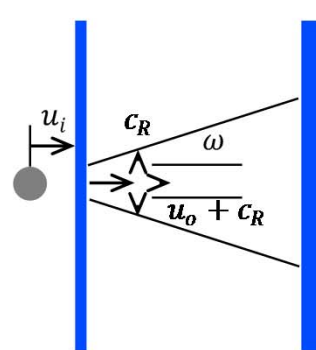
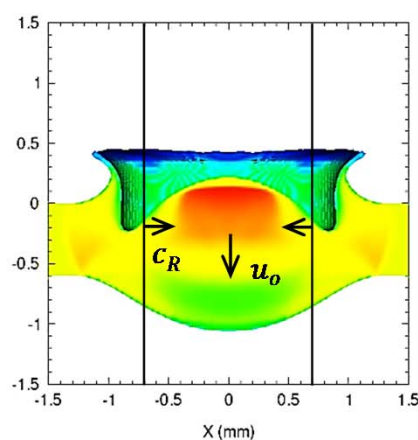


Al (U-u) Data: Shockwave Database

Expansion about the center of mass occurs in all directions at the sound speed of the compressed material

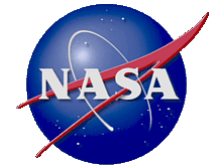


Aluminum

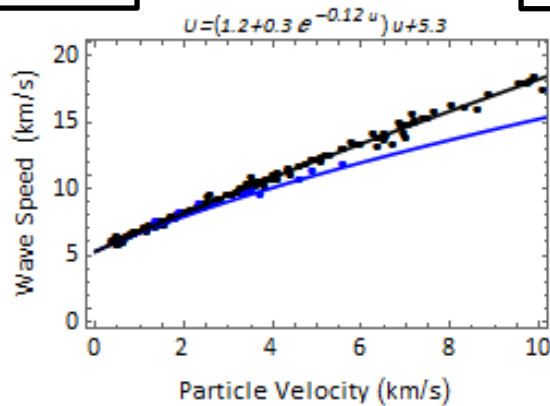


Black: Al Shock Wave Data from Shockwave Database
Blue: Al Release Wave Data from Shockwave Database

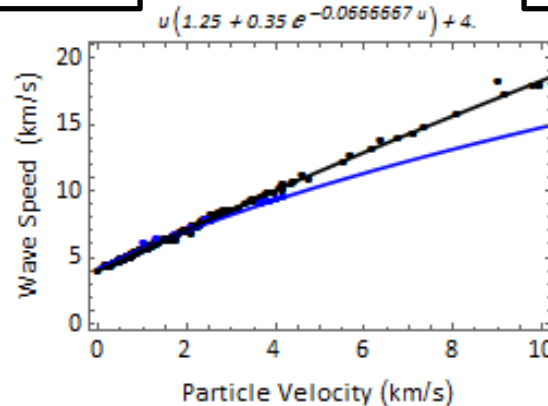
Using the same approach to describe the release wave speeds can describe a broad range of materials



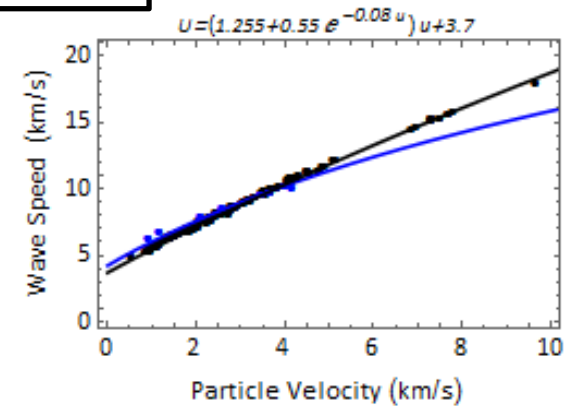
Aluminum



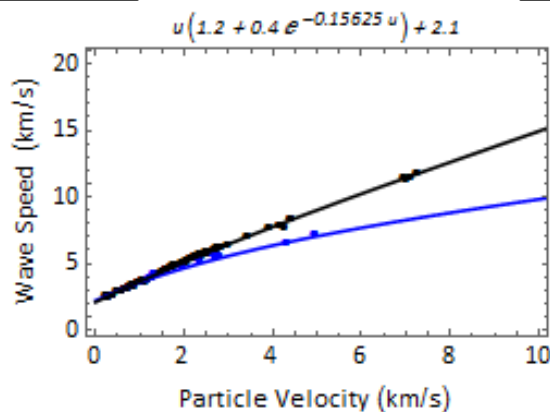
Copper



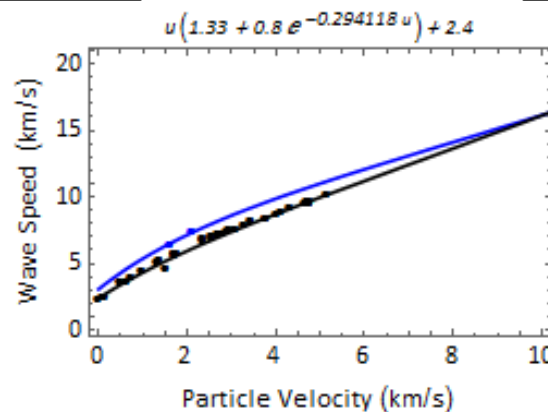
Iron



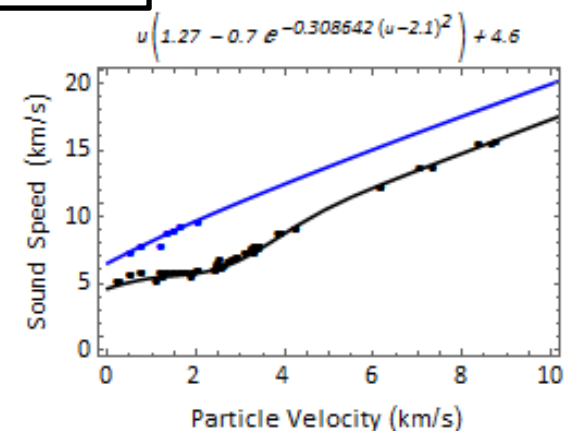
Lead



Nylon



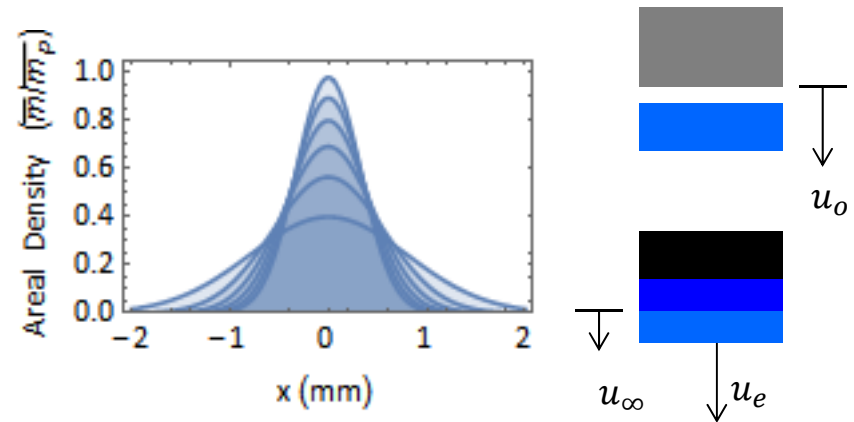
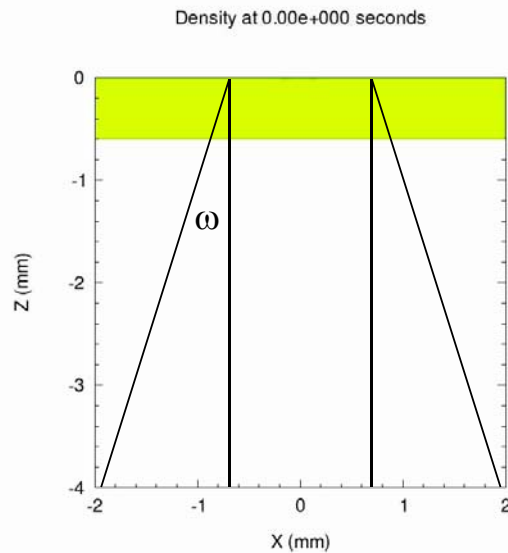
Quartz



The projectile thermally expands over the rear wall and stops when the particle velocity is lower than the material strength capability of the rear wall



Aluminum



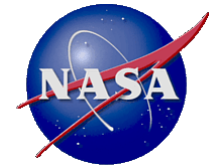
$$\omega = \frac{c_R}{c_R + u_o} \left(1 - \frac{u_o^2}{u_i^2} - \frac{\sigma_s \epsilon N}{1/2 \rho_W u_i^2} \right)$$

$$\sigma_s = \left(\frac{4 \rho c_R K^2}{\dot{\epsilon}} \right)^{1/3} \quad N = \frac{d \rho c_R^2 \sigma_U \epsilon}{4 K^2}$$

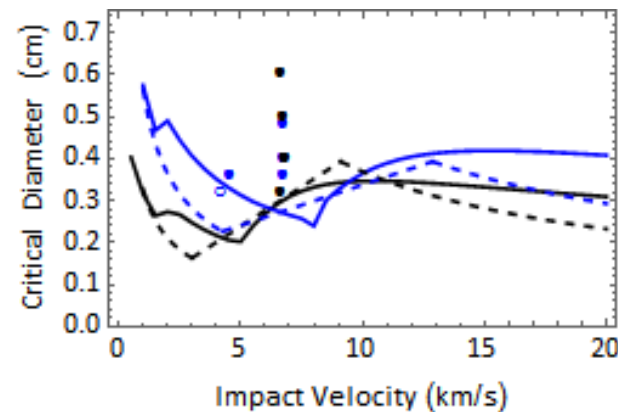
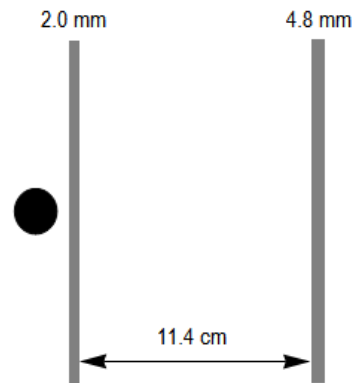
$$d_i = \frac{3}{2} \left(\frac{\bar{m}_W'}{\rho_i} \left(\sqrt{\rho^*/\rho_i} + \omega_i S/r_i \right) \frac{\hat{u}'}{(1 + \hat{R}_W') - \hat{u}'} - \frac{\bar{m}_W}{\rho_i} \left(\frac{\sqrt{\rho^*/\rho_i} + \omega_i S}{\sqrt{\rho^*/\rho_i} + \omega_W S/r_i} \right) \right)$$

$$\hat{u}' = \left(\frac{u_F' + \frac{c_W'}{s_W' + 1}}{u_\infty' + \frac{c_W'}{s_W' + 1}} \right)^{\frac{2}{s_W' + 1}} \quad \hat{R}_W' = \frac{\rho_W' (s_W' u_\infty' + c_W')}{\rho_i (s_i (u_o - u_\infty') + c_i)}$$

With appropriate material models the consideration of a broad range of configurations and impact conditions

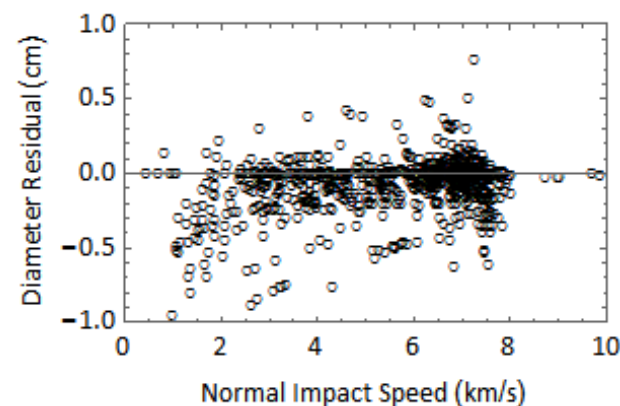
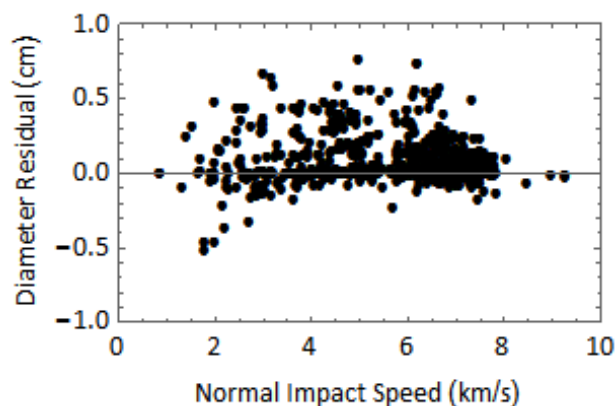


Steel



Open-Pass
Closed-Fail
Black-Normal
Blue-45° to Normal

- 1500+ double wall impacts have been performed and collected into a database
 - Impactors include Cadmium, Copper, Nylon, Glass, Aluminum, Alumina and Steel and many more
 - Impact speeds from 2 to 10 km/s and obliquities from normal to 75° to normal



Solid curve: This work
Dashed curve: NASA TP-2009-214785 with $V_{Hi} = 9.1$ km/s
Steel Data: Kalinski, M. E., OMB 0704-0188 (2004)

Hydrodynamic simulations have a large array of material input parameters that make understanding shields difficult without analytic understanding



Steel

- Equation of state
 - Mie-Gruneisen with shock wave reference/constant specific heat

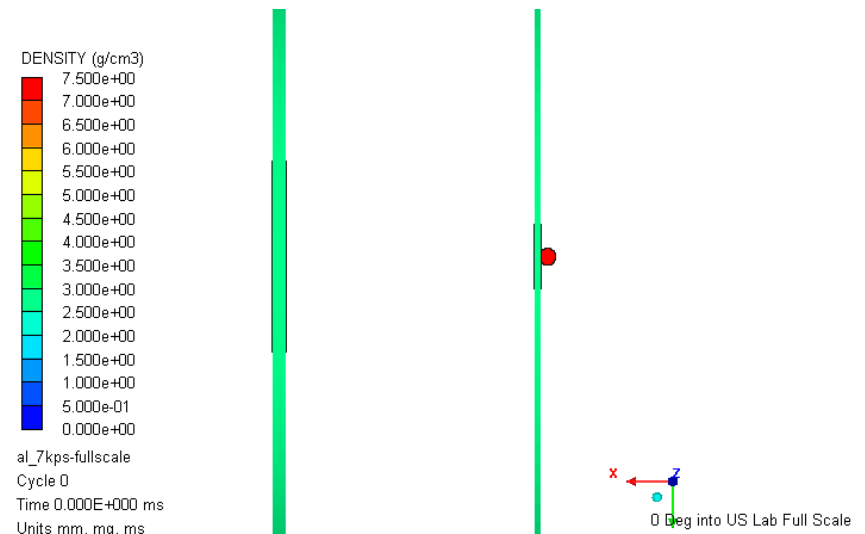
$$p - p_o = \Gamma_o \rho_o (e - e_o)$$
- Deviatoric model
 - Johnson-Cook with linear thermal dependence for first wall

$$Y = (A + B\epsilon^n) \left(\frac{(T_m - T)}{(T_m - T_o)} \right)$$
 - Johnson-Cook with fourth root strain rate for second wall

$$Y = (A + B\epsilon^n) \left(1 + (\dot{\epsilon}/\dot{\epsilon}_o)^{1/4} \right)$$
- Fracture model
 - Johnson-Cook with strain change proportional to strain and linear thermal degradation

$$\epsilon_F = D2 \text{Exp}[-D3 P/Y]$$

- **Density Effects Test #7**
- **Velocity: 6.7 km/s**
- **Projectile: 6-mm Diameter 440C Stainless Steel**
- **Bumper Plate: 6061-T6 Aluminum**
- **Catcher Plate: 2219-T87 Aluminum**



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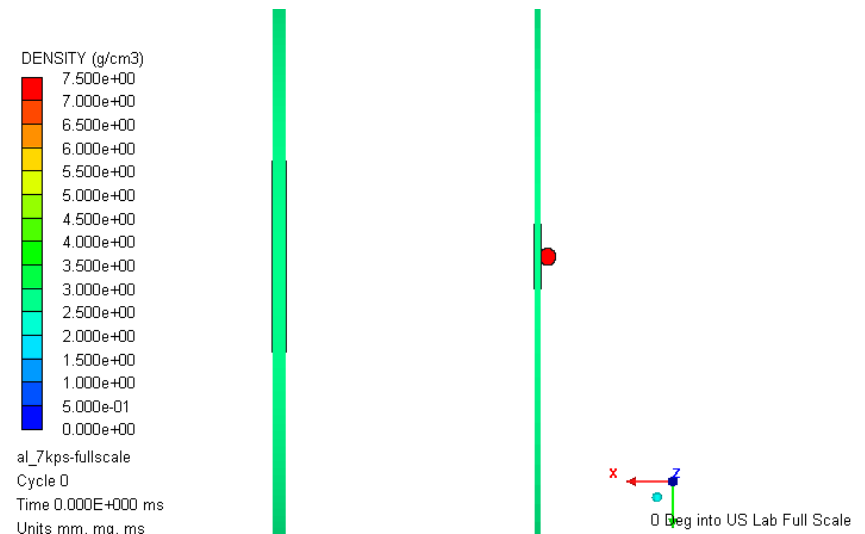
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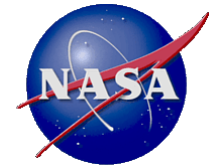
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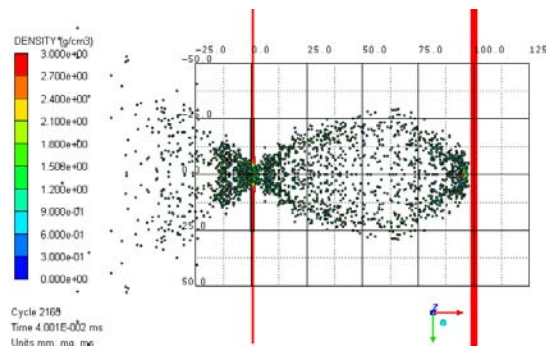
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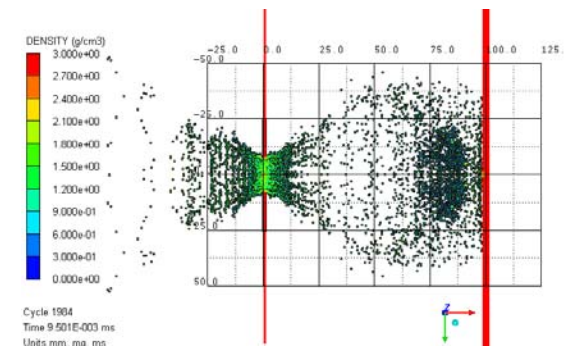
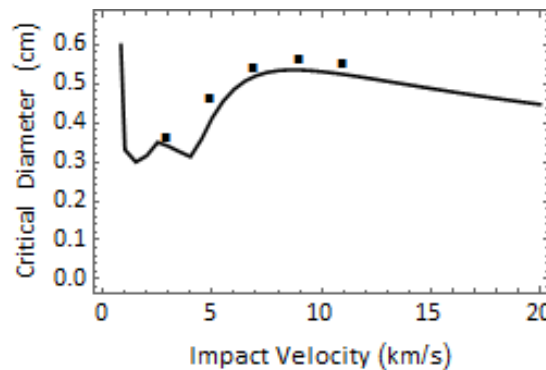
Using simulations with the analytic model yield insights into the role of material properties in expansion



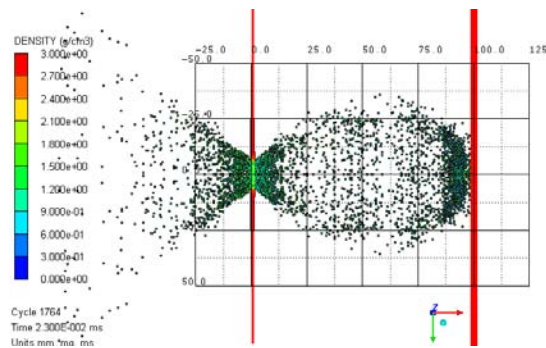
3 km/s



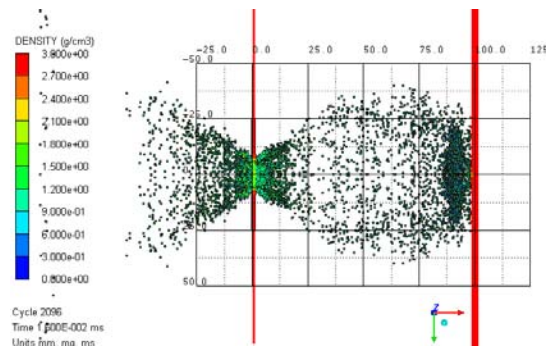
11 km/s



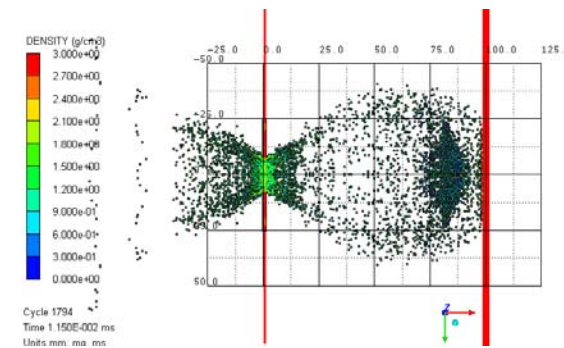
5 km/s



7 km/s



9 km/s



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